Textile UWB antenna for on-body communications

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ABSTRACT

This paper presents UWB textile antenna designed for Wireless Body Area Network (WBAN) applications [1]. Designed textile antenna offers a possibility of integration into clothing due to a small thickness (0.5mm) and flexibility. Measured return loss and radiation pattern characteristics of textile UWB antennas agree well with simulations. Moreover, measurements showed that this textile antenna has good transient performance when operating on the human body. In on-body communication scenario, transmitted pulses have similar duration (0.34-0.43ns) for different distances between the antenna and body (2-20mm).

1. INTRODUCTION

Wearable computing is a new, fast growing field in application-oriented research. Steadily progressing miniaturization in microelectronics along with other new technologies enables wearable computing to integrate functionality in clothing allowing entirely new applications. Integration in textiles ideally combines such requirements since clothing offers unobtrusiveness, a large area and body proximity. However, such electronic devices have to meet special requirements concerning wearability. For wireless connectivity of wearable/on-body devices ultra-wideband (UWB) technology is believed to be a favourable choice. UWB is an emerging wireless technology, recently approved by FCC for operation between 3.1 and 10.6 GHz. In low/medium data-rate applications, like wearable computing (or medical monitoring system), UWB offers possibilities of low-power operation and extremely low radiated power, thus being very attractive for body-worn, battery-operated devices.

In this paper we present UWB textile annular slot antenna for wearable applications, made entirely of textiles. Previous textile antennas were usually composed of dielectric materials with dielectric constant (ε_r) only slightly higher than one, and thicknesses of 4-8mm [2, 3]. A new feature of our UWB textile antenna is that it could be easily integrated directly into clothing, rather than being attached, since they are only 0.5mm thick.

2. TEXTILE MATERIALS FOR ANTENNAS

As a conductor we have used high conductive metallized Nylon fabric - Nora [3]. Its three metallized layers (Ni/Cu/Ag) provide high conductivity (surface resistivity of 0.03Ω/sq.) and protection against corrosion, as well as flexibility. We chose an acrylic fabric of 0.5mm thick as a dielectric substrate. We used technique explained in [4] in order to extract the permittivity of the textile substrate. This technique utilizes S parameter measurements of two transmission lines of different lengths. Knowing the length difference and the S-parameters, a permittivity of 2.6 (+/-0.1) between 3 and 10 GHz was extracted for the acrylic textile. The thickness of the dielectric is not only important for easy integration with clothing, but should also provide the possibility to realize a feeding transmission line of appropriate characteristic impedance (in our case 50Ω). It is an important issue in the design of textile antennas.

3. ANTENNA DESIGN

In Figure 1 we present the designed UWB annular slot antenna, fed by a short microstrip line. This antenna type is known to have good transient characteristics [5]. Commercial full-wave electromagnetic solvers CST Microwave Studio and HFSS were used during the design. The radiating slot was realized with a use of two conductive layers. The planar antenna size is 30x30 mm^2.

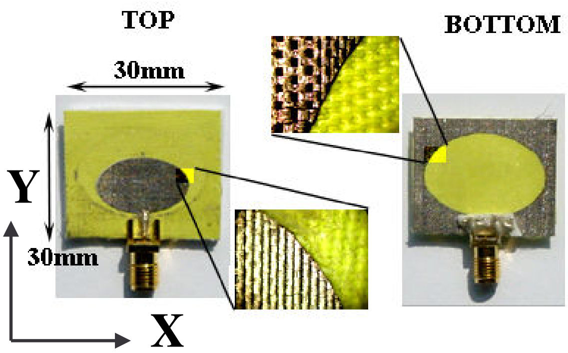

Figure 1. Textile UWB annular slot antenna.

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4. RESULTS

4.1. Return loss

Figure 2 presents comparison between measured and simulated return loss (RL) characteristics. To have an idea about the repeatability of the antenna manufacturing, we have built two prototypes (S1, S2) of the same design. It should be mentioned that manufacturing methods used are simple and antennas are ‘hand-made’. Antennas have good input matching below -10dB, measured and simulated results agree well. Small discrepancies can be associated with antenna manufacturing and connections. Comparing two textile antenna prototypes, S1 and S2, we can see that return loss characteristics are similar, the biggest difference occurs between 9 and 10 GHz.

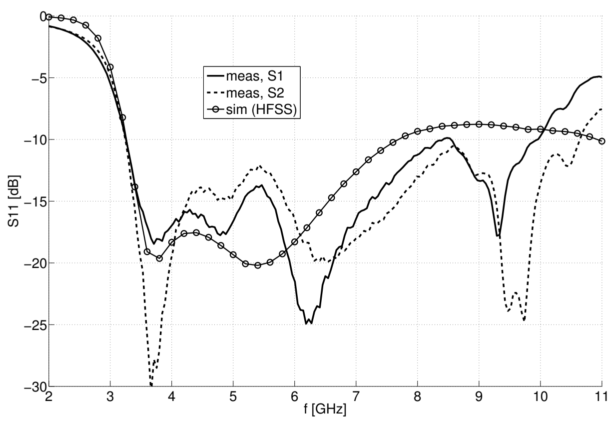

Figure 2. Measured and simulated free-space return loss characteristics. S1 and S2 are two antenna prototypes manufactured for repeatability check.

During the design process textile materials were modeled considering only their electrical parameters, conductivity and dielectric constant. Specific composition of textile was not considered. Agreement between measured and simulated results has proved that this approach was correct, and any discrepancy between two should be related to manufacturing difficulties and inaccuracies.

4.2. Free space radiation patterns

In Figure 3 we compare measured and simulated radiation patterns at 3.1, 6 and 9 GHz, for two major cut-planes, XZ and YZ. Beside the pattern in the XZ plane at 9 GHz, where the difference is rather significant, simulated and measured patterns show good agreement. We can see that practically in the entire frequency band of operation (3-10 GHz) the same amount of power in radiated in both hemispheres. This quasi-omnidirectional radiation will change in on-body communication scenario [6, 7]. Human body which appears in the lower hemisphere below the antenna (90:270deg in Figure 3) absorbs/reflects significant amount of antenna near-fields [7].

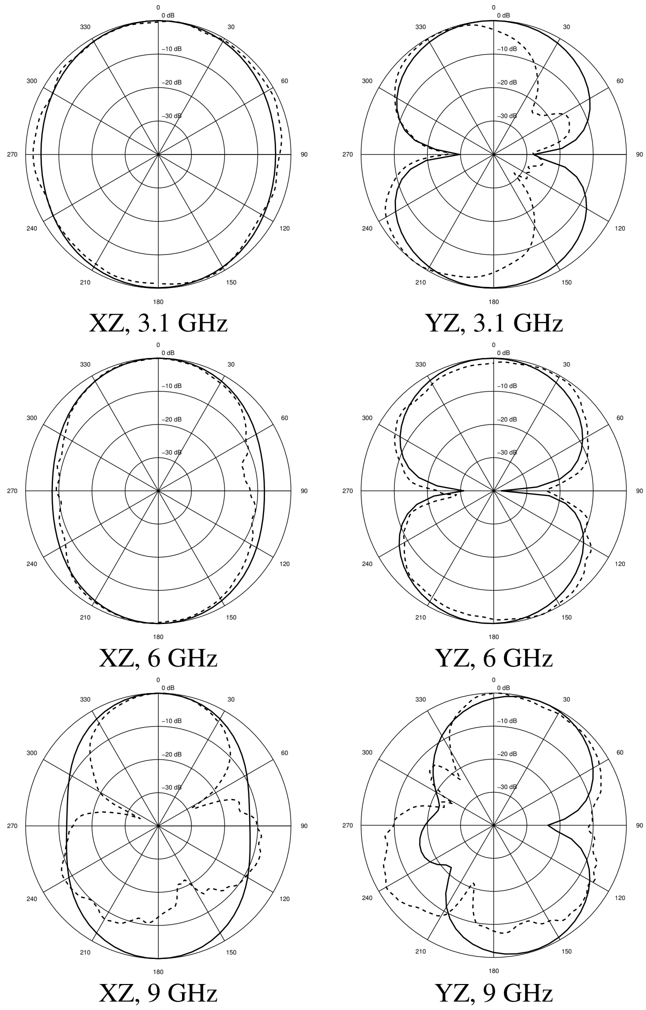

Figure 3. Measured and simulated free-space radiation patterns.

4.3. On-body time-domain characteristics

To investigate the on-body transient performance, we have mounted two textile antennas on a chest (Tx antenna) and on an abdomen, 15cm apart. Measurements were performed in the frequency domain (between 2 and 11 GHz) using vector network analyzer. Time domain responses (transmitted pulses) were calculated by multiplying measured responses and spectrum of the input pulse, and then applying inverse Fourier transform. Input pulses are presented in Figure 4. Pulse P1 bandwidth (on -10dB level) covers 3-9 GHz frequency range. Pulse P2 has -10dB bandwidth from 3 to 6 GHz.

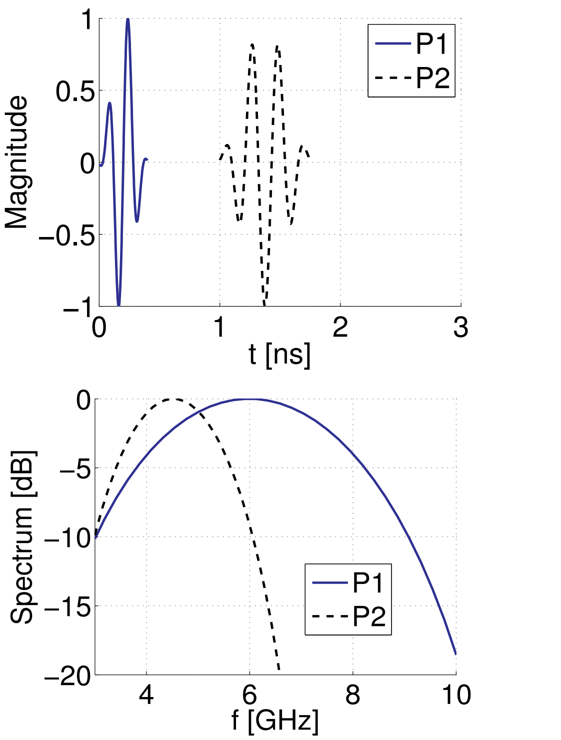

Figure 4. Input pulses used for calculating on-body transient responses.

Measured transmitted pulses (input pulse P1) for on-body link are presented in Figure 5. Pulse transmitted between in free-space is shown as the reference. Distance between the body and an antenna was: 2, 6, 10, 15 and 20mm. In a single measurement we kept the same antenna-body distance for the Tx and Rx antenna. All pulses in Figure 4 are normalized to the same value (maximum amplitude of the free-space pulse), thus direct comparison of pulses is possible.

Results in Figure 4 show that for all investigated distances between the antenna and body transmitted pulses do not significantly differ in duration (0.34-0.43ns). But the difference in the amount of energy transmitted is easily noticeable. Not surprisingly, the lowest energy is transmitted when antennas are 2mm from the human body. As distance between the body and antennas increases, also pulse's energy increases. There is however only 10% difference in the pulse energy for distances between 2 and 10mm. At 15 mm distance the pulse energy is close to that in the free-space. Table 1 quantitatively compares transient parameter of on-body communication, and also free-space link for reference.

For 20mm distance, the energy transmitted along the body is 2.3 times higher than in free-space. Similar result was reported in [7], but for a transmission between on-body Tx antenna and off-body Rx antenna (antennas face-to-face). This phenomenon can be related to a high reflectivity of human tissues at higher frequencies, and also to higher antenna directivity.

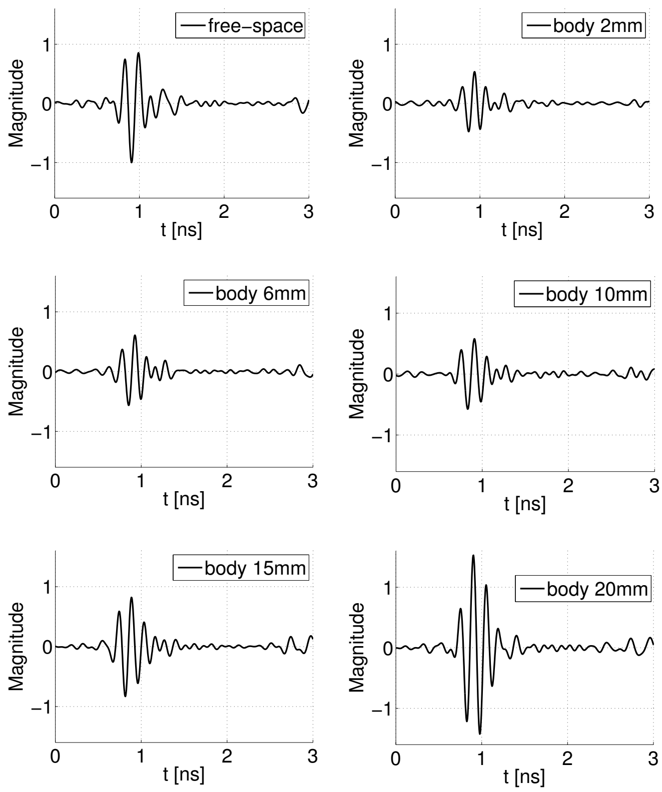

Figure 5. Measured free-space and on-body transmitted pulses for input pulse P1 (3-9GHz 10dB bandwidth). Distance between the body and antennas: 2, 6, 10, 15 and 20mm.

	Fidelity [%]	**Energy [%]**
Free space	100	100
2mm	80	30
6mm	85	40
10mm	91	42
15mm	90	81
20mm	83	236

Table 1. Transient parameters of pulses transmitted on-body for different distances between antenna and body. Input pulse is P1. Values are normalized to the free-space pulse.

To further investigate aforementioned behaviour, we have calculated transmitted pulses assuming pulse P2 as the input excitation. Pulse P2 covers lower frequency band of UWB, from 3 to 6 GHz. Results are presented in Figure 6. Again, we observe significantly attenuated pulse for 2mm distance between the antenna and body, compared to free-space scenario. But unlike in Figure 5, we observe that for 20mm distance, transmitted pulse has comparable (actually lower) energy with free-space case. Above results would suggest that higher frequency band of the approved UWB spectrum is more suitable form the antenna and propagation standpoint.

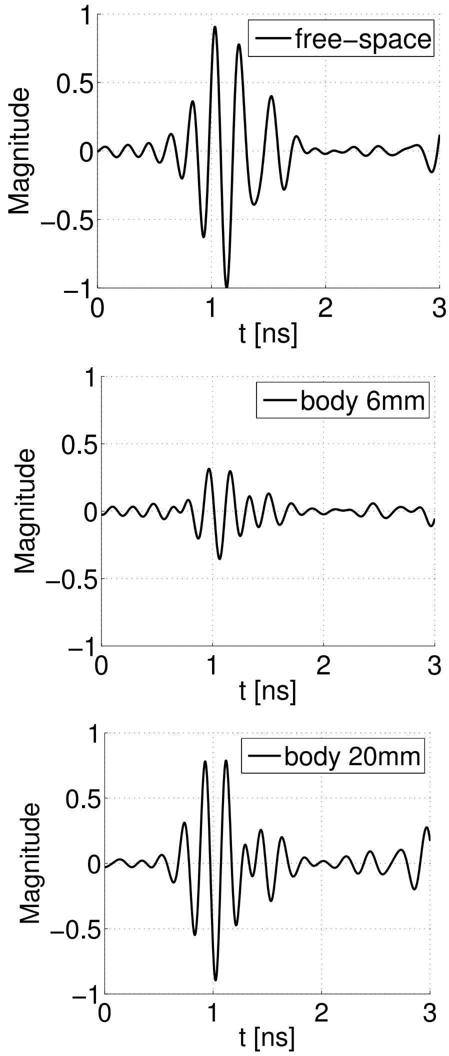

Figure 6.Measured free-space and on-body transmitted pulses for input pulse P2. Distance between the body and antennas: 6 and 20mm.

5. CONCLUSIONS

Textile UWB annular slot antenna for WBAN applications was presented in this paper. The antennas have small physical size and can be easily integrated into clothing. Results confirmed the good transient performance over UWB frequencies. In on-body communication scenarios pulses of around 0.35ns can be transmitted. With varying distance between wearable antenna and body duration of transmitted pulses changed little, but significant differences in energy of radiated pulses have been disclosed.

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